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Generation of Error Signals by Ring Tracker

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Abstract: This paper introduces some technical approaches by which a ring tracker can generate error signals, namely: the analog digital circuit method and the computer data processing method. Also, it derivates an error-based information mathematical model and discusses how to redesign error properties with a computer software method.

Key words: Ring tracker, error signal, computer information processing

1 Introduction

The ring tracker was developed only in recent years. It is now being applied to the coastal defense-oriented jamming-proof infrared final guidance seekers and small-scale jamming-proof infrared seekers. It enjoys fairly high optical efficiency because its optical system has no secondary optics and no modulation plate, and has high sensitivity because the photosensitive area of the detector is very small. In addition, this tracker has a rather small instantaneous field of view and rather high spatial resolution in the radial direction, which serves as a foundation for jamming-proof information processing.

With circular symmetry and insensitivity to the missile spin frequency, this tracker is suitable for seekers operating with regard to a missile spin system. It can produce required error signals without conducting the complex coordinate conversion as in the case of the "Cross" plan. Such a tracker can process

information in a simple way and easily generate error signals by using several methods including the digital analog circuit method and computer software method.

2. Error Signals Generated by Digital Analog Circuit

The secondary mirror of the location marker can execute a conical scan at a fixed modulation frequency, and the center of the target image spot scanning circle, relative to the center coordinates of the ring detector, represents the target location in space. The location marker turns the continuous infrared radiation of the target into sets of infrared radiation pulses, which are then converted to electric signals in the detector. When scanned across the ring detector, the target image spot generates twin pulse signals. Fig. 1 is a schematic diagram showing the conical scan of the ring detector.

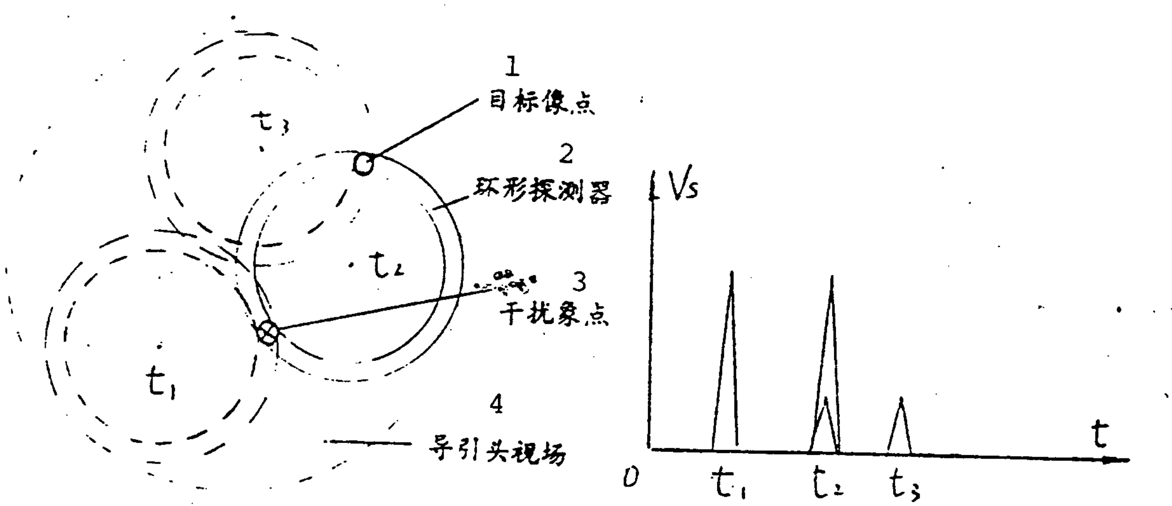

Fig. 1 Schematic Diagram of Conical Scan of Ring Detector

Key: (1) Target image spot; (2) Ring detector;
(3) Interference image spot; (4) Seeker field of view

When the scanning circle is scanned across the ring detector, it can produce two pulses, which, processed through the pulse generation circuit, turns into a pulse with a width τ. The fundamental wave component (amplitude value) and direct current component of this pulse are:

$$V_S = A/\pi^{*}(4R^{2}-l^{2})/R \tag{1}$$

$$V_D = A/\pi^{*}\cos^{-1}(l/2R) \tag{2}$$

where A--pulse width

R--radius of scanning circle

I --deviation volume of scanning circle (i.e. target deviation volume)

Plot an error property curve in accordance with Eq. (1) as shown in Fig. 3(a). This property is a relay property unfavorable for the tracking system and thereby needs further linearization. Fig. 2 is a block diagram showing the principle of the linearization processing circuit.

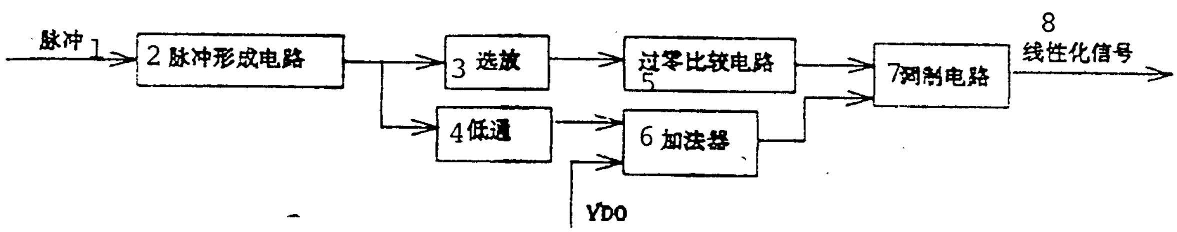

Fig. 2 Block Diagram Showing Principle of Error signal Linearization Processing

Key: (1) Pulse; (2) Pulse generation circuit; (3) Selected amplification; (4) Low pass; (5) Over zero comparison circuit; (6) Adder; (7) Modulation circuit; (8) linearized signal

The pulse generation circuit outputs a pulse with a width ranging from 0 to 5ms, depending on target location. One of its execution approaches is to single out the fundamental frequency signal of the modulation frequency, which, through zero comparison, turns into a normalized square wave and outputs at one end of the modulator. The other execution approach selects, through low-pass filter, a direct current signal V_D and outputs it at the other end of the modulator. The amplitude of the signal that the modulator outputs is determined by the direct current signal while its phase is determined by the alternate current signal. This way, the linearization of the error signal is realized. The error property after linearization is shown in Fig. 3(b).

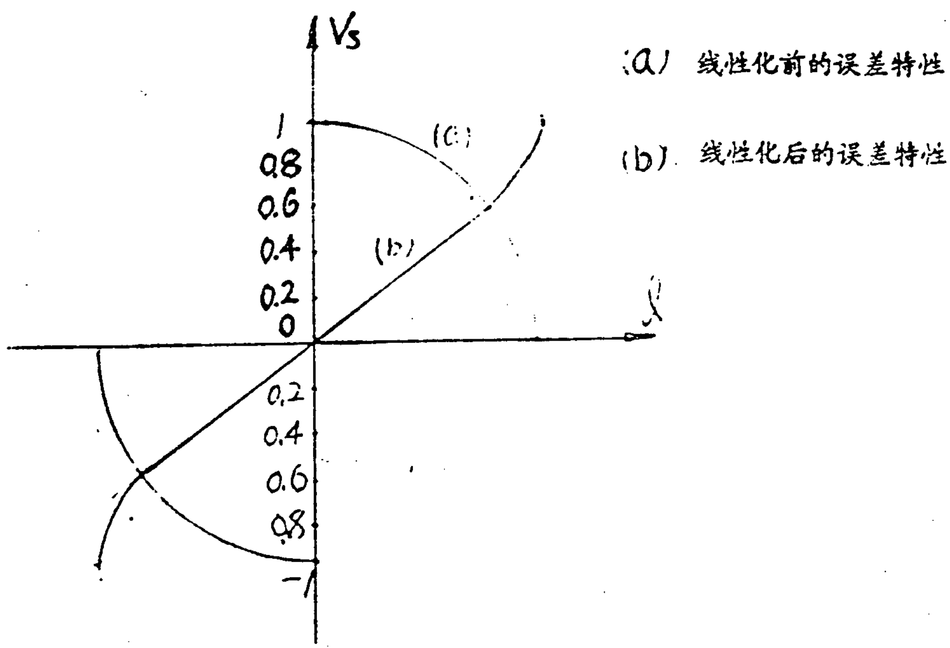

Fig. 3 Error Property Curve Before and After Linearization

Key: (a) Error property before linearization
(b) Error property after linearization

3. Error Signals Generated by Computer Software

A 16-bit 8098 monolithic processor system is used in the information processing of error signals. This processor was developed by the Intel Corporation in the United States in 1988 and now is regarded as one of the more advanced monolithic processors worldwide. With a 16-bit CPU word length in its inner bus and a quasi-16 of an 8-bit structure in the outer bus, it is particularly suitable for a real-time system with a small volume, high reliability and complex control.

In the ring detector error-signal mathematical model, ρ and θ are two parameters in polar coordinates, which represent the deviation volume of the target image spot in seeker coordinates. Once the mathematical expression for ρ and θ is solved, the error signal mathematical model needed for the computer software can be acquired as shown in Fig. 4.

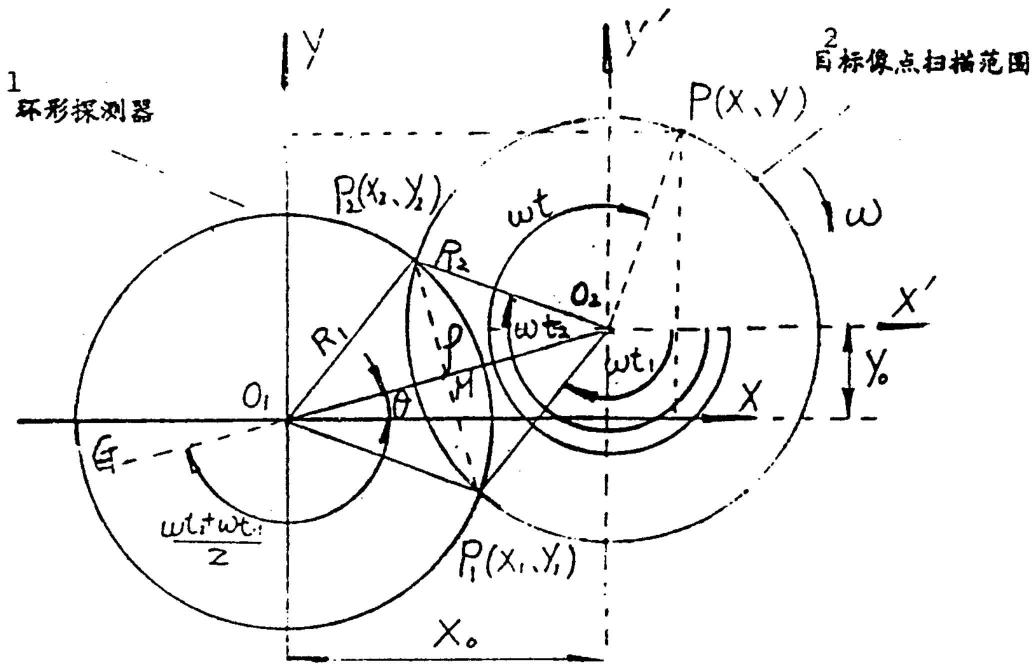

Fig. 4 Error Signals Generated by Ring Tracker

Key: (1) Ring detector
(2) Target image spot scan range

$$\begin{cases} x = x_0 + R_2 \cos \omega t \\ y = y_0 - R_2 \sin \omega t \end{cases}$$

When $t=t_1$, two circles intersect at the point $P_1(x_1, y_1)$ and outputs pulse signal 1.

When $t=t_2$, two circles intersect at the point $P_2(x_2,y_2)$ and outputs pulse signal 2.

$x_1=x_0+R_2 \cos\omega t_1$, $y_1=y_0-R_2 \sin\omega t_1$

then

$x_2=x_0+R_2 \cos\omega t_2$, $y_2=y_0-R_2 \sin\omega t_2$

The mathematical expression of the error signals ρ and **θ** is as follows:

$$\rho = R_2 \frac{a(t_2 - t_1)}{2} + \sqrt{R_1^2 - R_2^2 \sin^2 \frac{a(t_2 - t_1)}{2}} \tag{1}$$

Since the target image spot scanning circle is required to match the ring detector in dimension in engineering, $R_1=R_2=R$ and Eq. (1) can be simplified as:

$$\rho = 2R\cos\frac{a(t_2 - t_1)}{2} \tag{2}$$

$$\theta = \pi - \frac{a(t_2 + t_1)}{2} \tag{3}$$

It is known from Eqs. (1), (2) and (3) that ρ and **ω** are the functions of t_1 and t_2, i.e.

$$\begin{cases} \rho = f(t_1, t_2) \\ \theta = y(t_1, t_2) \end{cases}.$$

t_1 and t_2 are target location information which can be easily acquired through approximate calculations.

The makeup of the computer information processing system is shown in Fig. 5.

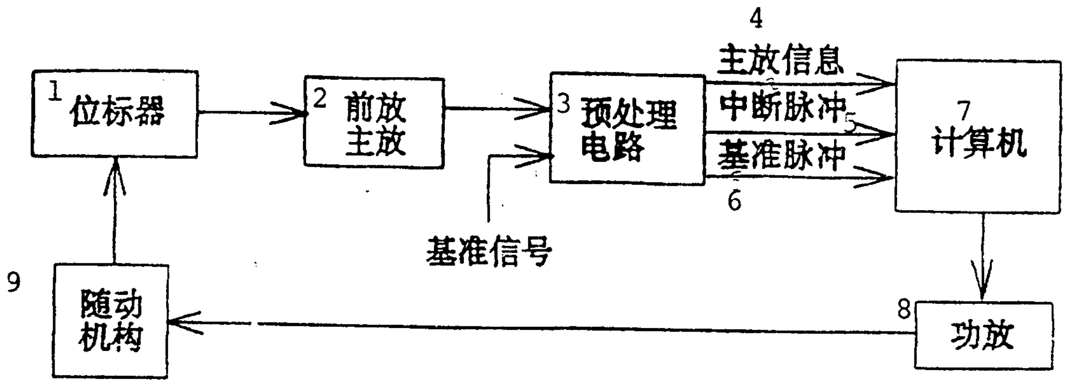

Fig. 5. Block Diagram of Computer Data Processing

Key: (1) Location marker; (2) Front amplification, main amplification; (3) Pre-processing circuit; (4) Main amplification data; (5) Interrupt pulse; (6) Reference pulse; (7) Computer; (8) Power amplification; (9) Follower

The location marker transforms the continuous infrared radiation of the target into sets of infrared radiation pulses, which are then converted to electric signals through the detector. With each rotation of the secondary mirror, one value of t_1 and t_2 appears, i.e., the target space location data are sampled once a period. The sampled values from adjacent periods may change with the target motion law, and a series of T value appears at equal intervals in regular periods. Although this value is a discrete value, its envelope line displays a certain variation law, and a set of T derived in each period can be regarded as a function of T varying with period N, i.e.:

$$t_1=z_1(n)$$

$$t_2=z_2(n) \qquad n=1,\ 2,\ 3,\ldots$$

The ρ and θ values are calculated by the computer from T sampling in each period, the period of the amplitude modulation square wave output by the computer is determined by the modulation period, the amplitude value of the square wave is determined by the ρ value, and the phase of the square wave is determined by the θ value. In the case of an alternate current

servo system, a particular error signal can be inputted, after selected amplification and power amplification, into the follower to realize target acquisition and tracking. Alternatively, with a direct current servo system, through phase-sensitive detection, it can be converted to a rectangular coordinate error signal.

A computer takes a certain operating time to accomplish information processing. It requires a delay of two periods to perform sampling of target location and amplitude information and to calculate the ρ and θ values, and then output the error signal to power amplification. Yet engineering practice demonstrates that the control system permits only a limited delay. A certain infrared seeker employed computer software to generate an error signal and reached a maximum tracking capability of 25°/s, which satisifes the mission requirements.

4. Redesign of Error Property Through Computer Information Processing

The error signal property serves as a critical technical index for the infrared guidance system. For instance, stringent requirements are set for a linear zone, blind zone or reverse zone. The ring tracker can derive the required error property by modulating the size of the scanning circle, while the technology of adjusting scanning circle is too complex to master. Therefore, engineering technicians usually obtain the required error property through repeated debugging based on their own experience.

The computer information processing technique can correct and upgrade the existing error property. In other words, the computer first conducts a "rough modulation" over the scanning circle to make it basically match the ring detector, and then designs the property in accordance with technical requirements, such as the error property curve shown in Fig. 6. Finally, it

redesigns the existing error property through designing the error property software.

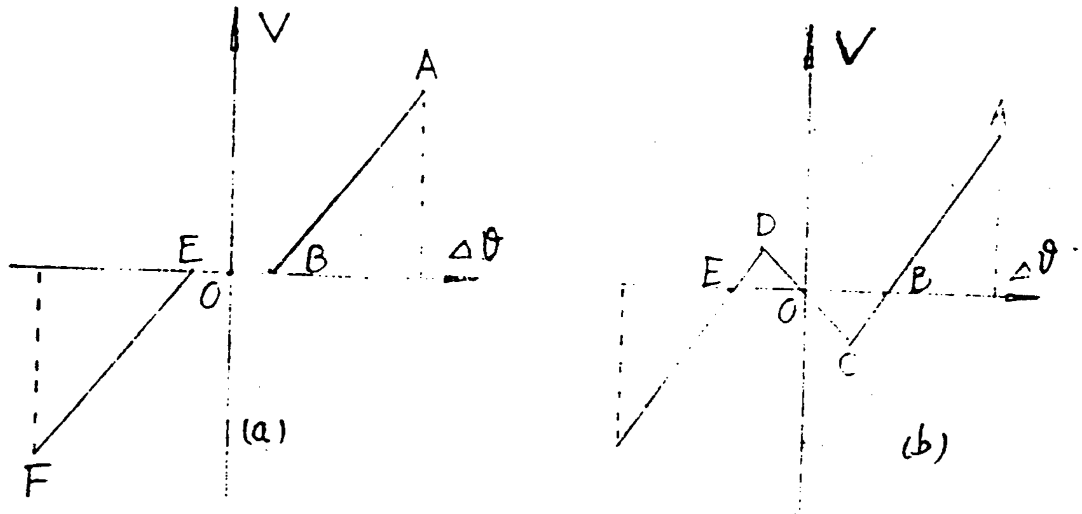

Fig. 6. Error Property Curve

For instance, the mathematical expression of error property in Fig. 6(A) is:

$$\begin{cases} |\Delta t| \geq 5 & 0 \\ 0.2 < |\Delta t| < 5 & 2R \bullet k \bullet \cos\dfrac{a(t_2 - t_1)}{2} \\ |\Delta t| < 0.2 & 0 \end{cases} \qquad \text{where} \quad \Delta t = t_2 - t_1$$

The linear zone, blind zone and slope parameters of this property can all be redesigned within a certain range through software. This method is virtually a supplement to the conventional scanning circle debugging technology. Software was used to improve the system error property in the development of the coast defense-oriented jamming-proof infrared final guidance seeker and acquired a positive result.

To summarize, the computer data processing approach is greatly superior to the analog digital circuit approach. On

condition that computer hardware structure does not need modification, the software, after an integrated design, can simultaneously realize a number of functions, including automatic control of main amplification gain, location marker locking, target identification, acquisition, tracking and memory. It is for this reason that the computer data processing technology has been widely applied to the infrared guidance systems.